METHODOLOGY FOR ASSESSMENT OF UNDISCOVERED CONVENTIONAL ACCUMULATIONS

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The estimation of sizes, numbers, and types of undiscovered, conventional accumulations of oil and gas remaining to be found onshore and within the State waters of the United States is based mainly upon play analysis.

A play is a set of known or postulated oil and (or) gas accumulations sharing similar geologic, geographic, and temporal properties such as source rock, migration pathway, timing, trapping mechanism, and hydrocarbon type.

Play analysis, for the purposes of this assessment, is the systematic evaluation of information and concepts concerning defined plays for the purpose of the development of a set of consistent hypotheses concerning amounts of additional reserves expected to be added within the play.

One or more geologists, selected for their research interests and experience, agreed to be responsible for one or more of the seventy-one provinces of the United States (Fig. 1). Each of these province geologists, working in consultation with province geologists in adjacent provinces, was responsible for the review of available literature and data and for seeking out and consulting with experts from industry, State geological organizations, and academia for the purpose of defining appropriate plays for assessment within his or her province. An initial set of play definitions was developed for review within the USGS and by scientists in various other organizations. After review, a more or less final set of plays was settled upon for the purposes of assessment. For each play, a concise play definition was retained and a specific geographic play boundary was established. These definitions and play boundaries are included in this CD-ROM.

A strength of play analysis is that it provides a link between the geologic concepts developed by the province geologist and the historical oil and gas information concerning exploration, drilling, discovery, and development within the play. Geologic concepts can be tested in light of historical information, and numerical data can be organized in meaningful ways for the purpose of postulating possible future activity. Most plays of undiscovered, conventional oil and gas accumulations fit into one of two broad categories: confirmed plays and hypothetical plays.

CONFIRMED PLAYS

A play is considered proven when one or more accumulations of minimum size (1 MMBOE) have been discovered within the play. Province geologists identified the known accumulations within their provinces and assigned them to the appropriate confirmed plays. Based upon the established play boundary and the reservoir and field assignments made by the province geologist, tables, maps, and plots were developed for each play. These included, but were not limited to, the following:

1. Tables of summary statistics of historical data for the play.
2. Plots showing accumulation size-frequency distribution by discovery thirds.
3. Plots showing depth of discoveries as a function of time.
4. Gas-Oil Ratio (GOR) or NGL to non-associated gas ratio for known accumulations.
5. Plots of accumulations discovered as a function of time.
6. Plots of accumulations discovered as a function of exploratory drilling.
7. Plots showing cumulative oil and (or) gas found as a function of time.
8. A plot of cumulative oil and (or) gas found as a function of exploratory drilling.
9. A plot showing depth versus API gravity of oil.
10. Plots showing depth versus average permeability and porosity.
11. A play boundary map with locations of fields and reservoirs.
12. A cell-based exploration intensity map showing degree of exploration in the play area.

These materials, many of which are included in this CD-ROM, were used as a supplement to geological information and concepts, for constraining the possibilities for undiscovered accumulations within the play.

HYPOTHETICAL PLAYS

In many cases the most interesting, albeit uncertain, plays in the National Assessment were those identified and defined based upon geologic information, but for which no accumulations of the minimum size had as yet been discovered. In contrast to confirmed plays, these hypothetical plays cannot, of course, be analyzed based upon trends in sizes, numbers, depths, and other properties of known accumulations. Rather,

properties of such undiscovered accumulations must be postulated based upon other types of information.

In practice, one of two methods is usually employed. The first of these is the application of a geologic analog. A suitable analog is a proven play that is geologically similar to the hypothetical play being assessed. The sizes and numbers of accumulations in the analog play are used, usually with some modification, to make estimates of undiscovered accumulations in the hypothetical play. The second approach usually entails direct simulation modeling of accumulations within the hypothetical play. This simulation approach (for example, see the analysis of plays in the Arctic National Wildlife Range published by Dolton and others in USGS Bulletin 1778) requires detailed information concerning structures and organic geochemistry of source rocks, as well as reservoirs, traps, and seals.

All available information is relevant. In short, the mission of the province geologist is to bring to bear on the hypothetical play any concepts and information that might help provide bounds on the range of possible resources to be expected in the play. Consequently, the hypothetical plays characteristically carry a much broader degree of uncertainty, as recorded in the range of possible resources reported, than do the confirmed plays. In addition to the greater range of reported resources, virtually all hypothetical plays carry a play-level risk.

RISKING STRUCTURE

Hypothetical plays share the interesting characteristic of not including a single discovered accumulation as large as the minimum size of 1 MMBO or 6 BCFG. It is therefore by no means certain that each of the hypothetical plays will ever contain such an accumulation. In order to express this uncertainty, a risking structure was developed based upon three geologic play attributes:

1. Charge is the quality and thickness of source rocks, their time-temperature history, and the timing of primary migration into the adjacent carrier beds.
2. Reservoir is both the presence and quality of reservoir rocks.
3. Trap is the entrapment structure, seal integrity, and temporal retention of hydrocarbons.

Province geologists were requested to provide an estimate of the presence and suitability of each of these attributes within the play for the existence of accumulations

of the minimum size. These estimates were expressed as decimal fractions between zero and one for each of the three attributes. The product of the three values (one for each attribute) is the play probability
(risk = 1 probability). Because the three play attributes are not necessarily always independent, care had to be taken not to apply multiple risks resulting from a single cause or event.

In addition to the strictly hypothetical plays, the risking structure was also occasionally applied to intensely explored and largely exhausted plays within which the finding of yet another accumulation of the minimum size was by no means certain. In calculating resources for hypothetical and largely exhausted plays, the play probability is applied to the product of the number and sizes of accumulations estimated to exist conditionally in the play.

Plays were not quantitatively assessed when the play probability was 0.10 or less.

THE TRUNCATED SHIFTED PARETO MODEL

For the purposes of this assessment, as in the previous USGS assessment (Mast and others, 1989), a model of the size-frequency distribution of the population of oil and (or) gas accumulations was assumed. The Truncated Shifted Pareto, or TSP model describes a "J-shaped" distribution in which ever-increasing numbers of accumulations occur in successively smaller size classes. The distribution is called shifted because it has been statistically moved to have its origin at the minimum accumulation size, in this case 1 MMBO or 6 BCFG. The TSP distribution is referred to as truncated, because, for the purposes of analyses, the distribution is cut off at the size of the largest accumulation in the distribution. For a detailed discussion of the TSP distribution, see Houghton and others (1993).

The TSP distribution was used in several ways in this assessment. The first use of the TSP was to provide a guide to the province geologists in their development of estimates of undiscovered accumulations. A TSP distribution was fit to the population of accumulations known from each play and, in chronological order of discovery, to the first third of the accumulations discovered, the second third discovered, and the last third. The results of these fitted populations were provided to the province geologists and review panels as source information regarding the changing size distribution of accumulations within the play as a function of time.

INPUT FOR RESOURCE ESTIMATION

Province geologists were requested to synthesize all available information and concepts in order to develop a set of hypotheses concerning undiscovered conventional accumulations within the proven or hypothetical play. These hypotheses were captured as a list of specific information requested from each province geologist. The requested information included:

1. Largest undiscovered accumulation in the play at a 5 percent (1 in 20) probability.
2. Absolute largest conceivable accumulation remaining to be discovered.
3. Median size of undiscovered accumulations greater than the minimum size.
4. Minimum, maximum, and most likely (median) number of undiscovered accumulations.
5. Depth distribution of undiscovered accumulations.
6. Hydrocarbon type (oil or gas).
7. Content of sulfur in oil or hydrogen sulfide in gas (ppm).
8. Types and amounts of non-hydrocarbon gases.
9. API gravity of undiscovered oil.
10. GOR (cubic feet gas/barrel oil)
11. NGL to associated gas and nonassociated gas in the play (barrels/million cubic feet gas).

Unless the province geologist had another specific model in mind, a TSP was fit to the median size and to the largest accumulation expected at a 5 percent probability in the postulated population of undiscovered accumulations, considering also the estimated maximum limiting value. The resulting TSP distribution was used to fill in the remaining fractiles of the size distribution of the undiscovered population.

The requested information for both hypothetical and confirmed plays was initially provided in written form. A review panel was then convened for whom the province geologist described each play in some detail and explained the strategies and rationale used in developing each piece of information provided on the form. The review panel, having seen and heard the work of the province geologist, then had three options.

1. Accept and endorse the findings of the province geologist without modification.

2. Recommend specific actions necessary to complete the analysis satisfactorily.

3. Recommend specific changes in the play information subject to consensus approval.

All three actions were commonly employed in the National Assessment.

Based upon sizes and numbers of accumulations of oil and (or) non-associated gas estimated as undiscovered in each play, resources of each of these commodities were calculated as a product, using a Monte Carlo simulation technique and applying play risk. After initial play-level assessments were completed, two additional levels of review were employed. First, a panel of specialists consisting of statisticians, geologists, and methodology experts met to review all results at a single sitting. Estimates were reviewed for internal consistency and compared with results of the last National assessment (Mast and others, 1989) and with special play-level and province-level discovery process models developed for this assessment by Drew and Schuenemeyer (1993) and Drew and others (this CD-ROM) . Large changes from the last assessment and results seemingly incompatible with the discovery process models were reviewed once again with the province geologist to make sure there were no obvious input errors or mistaken information. Errors in the input data were then corrected and the final play-level estimates were calculated by a Monte Carlo simulation.

Resources of gas associated with or dissolved in oil (associated/dissolved gas) were derived through use of estimated GOR's as applied to the calculated oil. Similarly, estimates of NGL were separately calculated for associated and non-associated gas by applying ratios provided by the estimators. Total gas and NGL at the play level was determined through summation.

SMALL FIELD ASSESSMENT

Probabilistic estimates of recoverable oil and gas in accumulations smaller than 1 MMBO or 6 BCFG of gas were made separately. The method for small-field estimation in this assessment is essentially the same as that used by Mast and others (1989) and described by Root and Attanasi (1993). The estimates were based on extrapolations of numbers of fields in field-size classes smaller than the play-analysis cutoffs (1 MMBO, 6 BCFG) using a log-geometric model. Estimates were made for provinces.

DENSITY DISTRIBUTIONS

Estimates of undiscovered resources are presented as a range of values corresponding to probabilities of occurrence in order to express the uncertainty inherent in assessment

of unknown quantities. The input variables of accumulation sizes and numbers are themselves expressed as density functions of uncertain quantities. The resulting cumulative probability distributions represent the quantity of undiscovered resources; from these distributions, various fractiles, including the low (F_{95}), the high (F_{05}) and the mean estimates are obtained.

AGGREGATION PROCEDURES

To arrive at the estimated quantity of undiscovered resources for larger areas, such as provinces, regions, or the Nation as a whole, distributions for the basic assessment units were progressively aggregated, with geological dependency incorporated at each level. In order to aggregate plays within provinces, geologic dependencies between plays were established for the three basic play attributes of charge, reservoir, and trap. Province geologists were requested to determine for each pair of plays in their province whether the correlation between plays of the pair was high (0.9), moderate (0.5), or low (0.1) for each attribute. Thus, to determine the degree of dependency of play A and B, if A and B are highly correlated with respect to charge (0.9), poorly correlated with respect to reservoirs (0.1), and moderately correlated with respect to trap (0.5), the mean value (0.9+0.1+0.5)/3 or 0.5 is determined. This mean value is considered the degree of dependency to be used in aggregating plays A and B. For the aggregation of province-level estimates, the provinces within each region were generally assigned a dependency of 0.5. In aggregation of regions for a National total, regions were generally considered to be independent.

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